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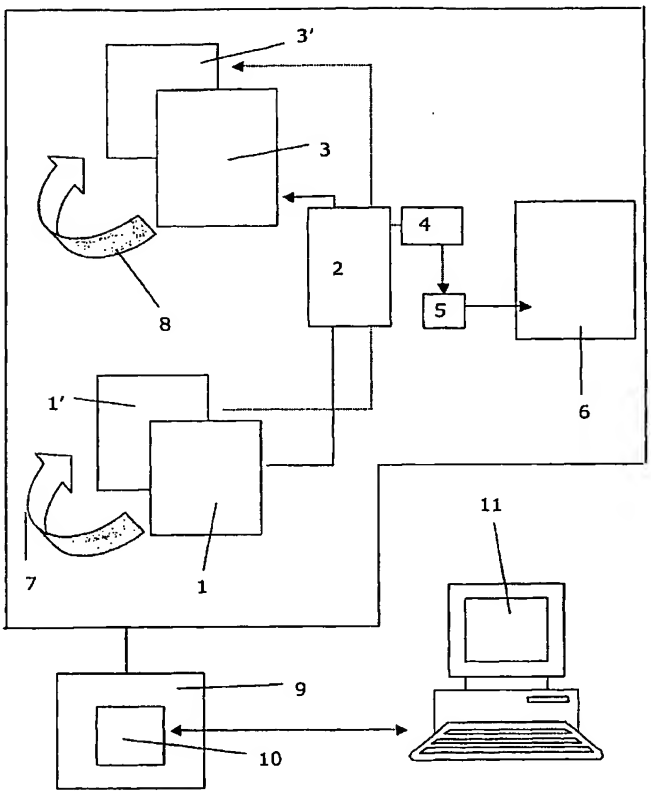
(54) Title: METHOD OF TOMOGRAPHIC IMAGING



(57) Abstract: The invention relates to a method of tomographic imaging, and in particular a CT or MR method, for the repetitive production of diagnostic slice images of a part of a patient's body. To allow a geometrical transformation (2) to be determined, current reference slice images (1) of the part of the body, which are brought into agreement with earlier reference slice images (3) of the part of the body are first made in this case. Current imaging parameters (5) are then calculated for a current diagnostic slice image (6) by transforming earlier imaging parameters by the geometrical transformation (2) previously determined. To give greater accuracy and, at the same time, a short image-making time, the image proposes that at least two current reference slice images (1, 1') be made, whose image planes are preset in such a way that their relative positions and orientations in three dimensions agree with the relative positions and orientations in three dimensions of the earlier reference slice images (3, 3'), the geometrical transformation (2) being determined in such a way that it brings all the current reference slice images (1, 1') in agreement with the corresponding earlier reference slice images (3, 3') simultaneously.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Method of tomographic imaging

The invention relates to a method of tomographic imaging, and in particular a CT or MR method, for the repetitive production of diagnostic slice images of a part of a patient's body, having the following method steps:

a) making of current reference slice images of the part of the body,

b) determination of a geometrical transformation by which the current reference slice images are brought into agreement with earlier reference slice images of the part of the body,

c) calculation of current imaging parameters by transforming earlier imaging parameters by means of the geometrical transformation determined in step b),

d) making of a current diagnostic slice image, the position and orientation in three dimensions of the image plane of the diagnostic slice image being determined by the current imaging parameters calculated in step c).

The invention also relates to a computer program and to a tomographic imaging unit having image-making means for performing the method.

Tomographic imaging methods, and particularly CT and MR methods, have proved to be powerful tools in the armory of modern-day medical diagnosis.

To enable pathological findings, such as advancing tumorous conditions for example, to be examined over fairly lengthy periods of time, it is necessary for diagnostic slice images of a part of a patient's body to be made repetitively at different times. Due to the different contrast characteristics of different imaging methods of examination, there are even diagnostic advantages to be drawn from slice images of an object for examination that are made under different modalities.

When diagnostic slice images are made as a repetitive process, it is crucial that the position and orientation in three dimensions, relative to the part of the patient's body that is being examined, of the slice images made at different times or under different modalities should agree as closely as possible so that, for example, the advance of the condition can be accurately observed. For this purpose, it is usual for reference slice images of the part of the body to be made before the actual diagnostic slice image is made. By calculating a geometrical transformation, it is possible for a fresh, current reference slice image that is

made to be brought into congruence with earlier reference slice images. The method that is required for this purpose is a method of optimization in which the sets of image data for the reference slice images made at different times are brought into agreement. From the geometrical transformation that is calculated, transformation parameters are obtained that are taken as a basis for calculating current imaging parameters. For diagnostic slice images, the current imaging parameters are then used to enable the image planes of the diagnostic slice images to be set repeatably (see for example J.M. Fitzpatrick, D.L. Hill and C.R. Maurer Jr.: "Chapter 8: Image Registration" in M. Sonka and J.M. Fitzpatrick (eds.) "Handbook of Medical Imaging, Volume 2: Medical Image Processing and Analysis", pages 447-513, SPIE Press, Bellingham WA, 2000; J.B.Maintz and M.A. Viergever: "A Survey of Medical Image Registration", Medical Image Analysis, Vol. 2(1), pages 1-36, 1998).

It is a disadvantage of the known methods that the accuracy obtained in calculating the imaging parameters is often not high enough. A particular reason for this is that the accuracy with which the geometrical transformation is determined is very much dependent on the presetting of the image planes of the reference slice images, because the resolution of the image in the image plane that is preset is, as a rule, considerably greater than in a direction perpendicular thereto. Because of the time required to make the reference slice images, it is not possible, and this is a disadvantage, for image data to be acquired, as part of the making of the reference slice images, with adequate resolution in all three dimensions. What would be needed for this purpose would be high-resolution volumetric imaging, something that is not possible in practice.

Taking the above as a point of departure, it is an object of the present invention to provide an improved method of tomographic imaging that allows accurate calculation of the imaging parameters required for the making of the diagnostic slice image and that manages with only a minimal image-making time for the making of the reference slice images.

In accordance with the invention, this object is achieved by a method of tomographic imaging of the kind mentioned in the opening paragraph in which there are made, in step a) of the method, at least two current reference slice images whose image planes are preset in such a way that their relative position and orientation in three dimensions agree with the relative position and orientation in three dimensions of the earlier reference slice images, and in which the geometrical transformation is determined in step b) in such a way that, by it, all the current reference slice images are brought into agreement with the corresponding earlier reference slice images simultaneously.

The finding on which the invention is based is that it is advantageous if, for calculating the imaging parameters, sets of image data from a plurality of current and earlier reference slice images, in which the relative positions and orientations in three dimensions of the image planes are preset at fixed values and are always the same, are brought into agreement simultaneously by means of a single geometrical transformation. By using a set comprising a plurality of reference slice images whose image planes are, if possible, differently oriented to determine the geometrical transformation, the image resolution that is actually available in this case in different directions in space is increased, but without it being necessary for any time-consuming high-resolution volumetric imaging having to be performed for the making of the reference slice images. Overall, there is an increase in accordance with the invention in the field of view (FOV) covered by the reference slice images as compared with methods known from the prior art, which has a beneficial effect on the accuracy and in particular on the unambiguousness with which rotations and translations of the part of body being examined are detected. In accordance with the invention, a plurality of reference slice images, whose individual resolution may be comparatively low, can be made in a short time. What is achieved by the method according to the invention is that low image resolution in a reference slice image in one direction of space is compensated for by correspondingly higher image resolution in another reference slice image in this same direction in space.

In the method according to the invention, the geometrical transformation may, for example, be determined in step b) of the method by identifying reference points in the current reference slice images that agree with corresponding reference points in the earlier reference slice images. By the finding of reference points that agree, regions of the image are defined at whose centers the reference points are respectively situated. The geometrical transformation is then the result of converting the coordinates of the reference points in the earlier reference slice images into the coordinates of the reference points identified in the current reference slice images. In this variant of the method according to the invention, the reference points that are to be converted into one another may, for example, be identified manually by a user, which he does by comparing the earlier and current reference slice images, which are displayed for this purpose on a suitable output unit, with one another and, in the course of this, selecting the appropriate points in the reference slice images interactively.

In the method according to the invention, it is found to be advantageous if the geometrical transformation determined in step b) of the method is a rigid or an affine

transformation that is defined by a corresponding set of transformation parameters. Rigid transformations, being a special case of affine transformations, define turning movements and displacements, i.e. rotations and translations, whereas affine transformations map points to points, straight lines to straight lines and planes to planes, in which case parallelism and relative lengths are maintained. Hence, it is possible with the rigid transformations to sense, for example, shifts in the position of the head of a patient being examined when the making of a diagnostic slice image is repeated.

In a variant of the method according to the invention that is an alternative or addition to the manual procedure described above for determining the geometrical transformation, the set of transformation parameters may be determined automatically by, by means of a suitable algorithm, optimizing a measure of similarity that represents the similarity of the current reference slice images to the corresponding earlier ones. To enable the set of transformation parameters by which the reference slice images are brought into agreement to be determined automatically, it is necessary for the similarity of the geometrically transformed current reference slice images to the corresponding earlier reference slice images to be quantifiable. What are suitable for this purpose are known measures of similarity such as, for example, the sum of the squares of the differences in the gray values of image points (SSD - sum of squares of differences) or the correlation coefficient (CC) or even measures of similarity used in information theory (e.g. MI - mutual information). The optimizing algorithms concerned are conventional algorithms such as, for example, the Gauss Newton or Downhill Simplex algorithm.

A plurality of parallel reference slice images in each of the head-foot, anterior-posterior and right-left directions are preferably made in step a) of the method, the image resolution being selected to be higher in the image planes than perpendicularly thereto. Hence, in accordance with the invention, low image resolution in the head-foot direction, for example, may be compensated for by high image resolutions in the other directions mentioned. It is advantageous that, in this way, only comparatively short imaging times are required for making the reference slice images.

A computer program as detailed in claim 5 is suitable for performing the method according to the invention, on for example a computer connected to a tomographic imaging unit. The software required for this purpose may advantageously be made available to users of tomographic imaging units on a suitable data carrier, such as a floppy disk or a CD-ROM, or over a data network (the internet) for downloading.

A tomographic imaging unit for performing the method according to the invention is the subject of claim 6, under which a computer is so set up in respect of software that the making of the diagnostic slice images takes place by the method described above.

These and other aspects of the invention are apparent from and will be elucidated with reference to the embodiments described hereinafter.

In the drawings:

Fig. 1 is a diagrammatic representation of the method of tomographic imaging according to the invention.

Fig. 2 is a view of reference slice images in the method of tomographic imaging according to the invention.

Fig. 1 is a diagram showing the making of a current reference slice image 1 of a part of a patient's body, which image is produced in particular by the MR or CT method of imaging. To allow a geometrical transformation 2 to be determined, an earlier reference slice image 3 is brought into agreement with the current reference slice image 1. From a set 4 of transformation parameters for the geometrical transformation 2, current imaging parameters 5 are then calculated, which are then used to set the position and orientation of the image plane of a diagnostic slice image 6.

It is ensured in this way that, as far as possible, the positions and orientations in three dimensions, relative to the part of the body being examined, of the diagnostic slice images made at different times or under different modalities agree.

In accordance with the invention, at least two current reference slice images 1, 1' are made. The relative positions and orientations, as symbolized by the arrow 7, of the reference slice images 1 and 1' agree in this case with the relative positions and orientations 8 of the corresponding earlier reference slice images 3, 3'. In a further step of the method according to the invention, the geometrical transformation 2 is determined in such a way that both of the current reference slice images 1, 1' are brought into agreement with the corresponding earlier reference slice images 3, 3' simultaneously. The set 4 of transformation parameters is determined automatically in this case by causing a measure of similarity that represents the similarity of the current reference slice images 1 and 1' to the earlier reference

slice images 3 and 3' corresponding thereto to be optimized by means of a suitable algorithm. The current imaging parameters 5 are then calculated on this basis.

The method according to the invention may be performed by means of a tomographic imaging unit 9 that has image-making means 10. The image-making means 10 make the reference slice images 1, 1', 3, 3' and the diagnostic slice image 6, with a computer 11 belonging to the tomographic imaging unit operating the image-making means 10 and calculating the imaging parameters 5 automatically by the method described above.

Fig. 2 shows that, for the making of reference slice images, the user of a tomographic imaging unit has available to him the foot-head (FH), anterior-posterior (AP) and right-left (RL) directions, in which the positions and orientations 12, 13 in three dimensions are different, in which case a plurality of parallel reference slice images 14, 15, 16 (so-called stacks) can be made in any of the directions mentioned.

By the method described above, current and earlier stacks of reference slice images can be used to calculate current imaging parameters.

CLAIMS:

1. A method of tomographic imaging, and particularly a CT or MR method, for repetitively producing diagnostic slice images of a part of a patient's body, having the following method steps:

a) making of current reference slice images (1) of the part of the body,

b) determination of a geometrical transformation (2) by which the current reference slice images (1) are brought into agreement with earlier reference slice images (3) of the part of the body,

c) calculation of current imaging parameters (5) by transforming earlier imaging parameters by means of the geometrical transformation (2) determined in step b),

d) making of a current diagnostic slice image (6), the position and orientation in three dimensions of the image plane of the diagnostic slice image (6) being determined by the current imaging parameters (5) calculated in step c),

characterized in that there are made in step a) of the method at least two current reference slice images (1, 1') whose image planes are preset in such a way that their relative positions and orientations (7) in three dimensions agree with the relative positions and orientations (8) in three dimensions of the earlier reference slice images (3, 3'), and in that the geometrical transformation (2) is determined in step b) in such a way that, by it, all the current reference slice images are brought into agreement with the corresponding earlier reference slice images simultaneously.

2. A method as claimed in claim 1, characterized in that the geometrical transformation (2) is determined in step b) of the method by identifying reference points in the current reference slice images (1, 1') that agree with corresponding reference points in the earlier reference slice images (3, 3').

3. A method as claimed in claim 1, characterized in that the geometrical transformation (2) determined in step b) of the method is a rigid or an affine transformation that is defined by a set (4) of transformation parameters, the set (4) of transformation parameters being determined automatically by, by means of a suitable algorithm, optimizing

a measure of similarity that represents the similarity of the current reference slice images (1, 1') to the corresponding earlier ones (3, 3').

4. A method as claimed in claim 1, characterized in that a plurality of parallel reference slice images (14, 15, 16) are made in each of the head-foot, anterior-posterior and right-left directions in step b) of the method, the image resolution being selected to be higher in the image planes than perpendicularly thereto.

5. A computer program for performing the method claimed in claim 1, which automatically determines imaging parameters by which the position and orientation in three dimensions of the image plane of a diagnostic slice image (6) are determined, so doing by

a) receiving current image data for current reference slice images (1) and earlier image data for earlier reference slice images (3) as an input,

b) determining a geometrical transformation (2) by which the current image data is brought into agreement with the earlier image data,

c) calculating the current imaging parameters (5) by transforming earlier imaging parameters by the geometrical transformation (2) determined in step b),

characterized in that the input in step a) comprises current and earlier image data for, in each case, at least two current (1, 1') and earlier reference slice images (3, 3'), and in that, in step b), the geometrical transformation (2) brings the image date for all the current reference slice images (1, 1') into agreement with the image data for the corresponding earlier reference slice images (3, 3') simultaneously, a set (4) of transformation parameters defining the geometrical transformation being determined by, by means of a suitable optimizing algorithm, maximizing a measure of similarity that represents the similarity of the current image data to the corresponding earlier image data.

6. A tomographic imaging unit (9) having image-making means (10) that make diagnostic slice images (6), and having a computer (11) that operates the image-making means (10) and for this purpose calculates imaging parameters (5) that determine the particular positions and orientations in three dimensions of the image planes of the diagnostic slice images (6), characterized in that the computer (11) is so set up in respect of software that the making of the diagnostic slice images (6') takes place by the method claimed in claim 1.

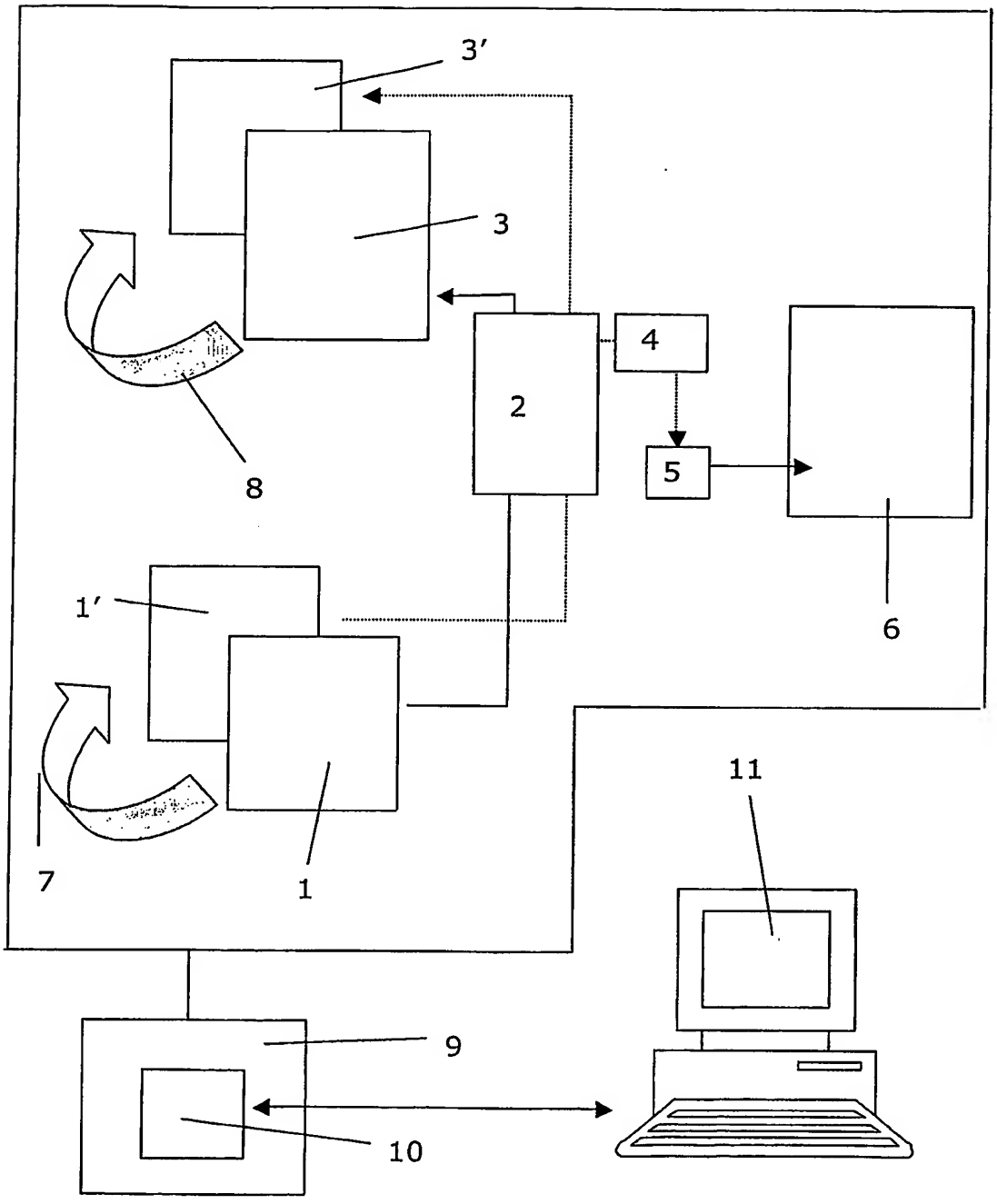

Fig.1

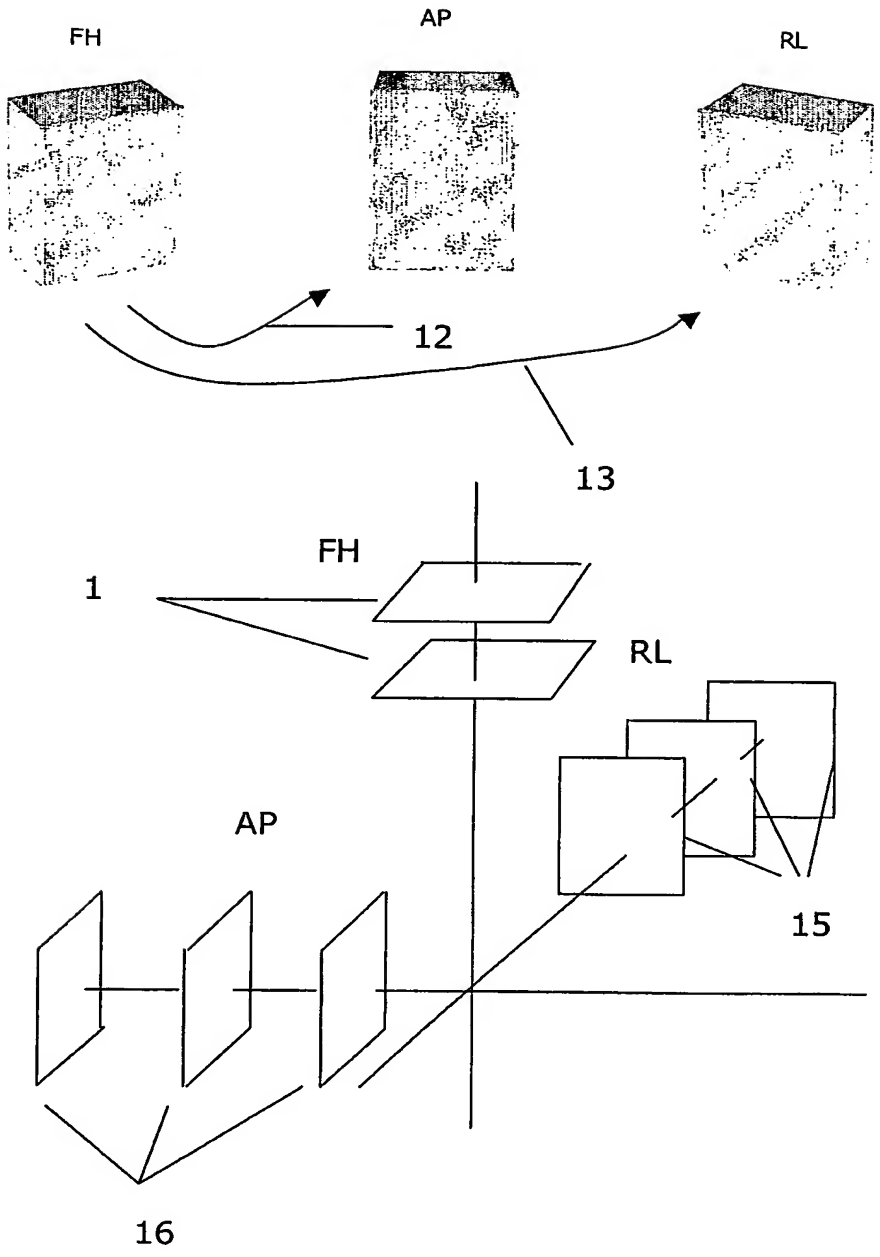

Fig.2

INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 A61B6/08

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 A61B G06T A61N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 98/02091 A (THE BOARD OF TRUSTEES OF THE LELAND STANFORD JUNIOR UNIVERSTIY) 22 January 1998 (1998-01-22) column 7, line 8 -column 10, line 29; figures 1-4,8,9 ---	1-3,5,6
A	WO 02/091924 A (KONINKLIJKE PHILIPS ELECTRONICS N.V.) 21 November 2002 (2002-11-21) page 3, line 27 -page 5, line 6 page 7, line 25 -page 8, line 33 figure 1 ---	1-3,5,6
A	US 6 195 409 B1 (CHANG ET AL.) 27 February 2001 (2001-02-27) abstract column 4, line 47 -column 6, line 27 figures 1-3 --- -/--	1,5

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

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Date of the actual completion of the international search	Date of mailing of the international search report
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INTERNATIONAL SEARCH REPORT

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 673 300 A (RECKWERDT ET AL.) 30 September 1997 (1997-09-30) column 4, line 62 -column 8, line 7 figures	1,5

INTERNATIONAL SEARCH REPORT

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